

CHAPTER 4

ELECTROMAGNETIC ENERGY

PHOTONS

Electromagnetic Energy

- The type of energy in x-rays, radio waves, microwaves & visible light

Properties of Electromagnetic Energy

- Frequency, Wavelength, Velocity & Amplitude

Energy Continuum

- An uninterrupted ordered sequence

Photon

- The smallest quantity of any type of electromagnetic energy
- It may be pictured as *quantum*
- *Waveform*: sinusoidal fashion

Quantum

- A small bundle of energy

An x-ray photon is a quantum of electromagnetic energy!

James Clerk Maxwell (Late 19th Century)

- He showed that visible light has both electric & magnetic properties

Velocity

- *c*: speed of light
- *Constant SI Unit*: 3×10^8 m/s
- *Constant British Unit*: 186,000 mi/s

The velocity of all electromagnetic radiation is 3×10^8 m/s!

Field

- The interactions among different energies, forces or masses

Gravitational Field

- It governs the interaction of different masses

Electric Field

- It governs the interactions of electrostatic charges

Magnetic Field

- It governs the interaction of magnetic poles

Sine Wave

- The variation in the movement of photons in electrical & magnetic fields
- Identical except for their amplitude

Amplitude

- The width of a waveform
- It is not related to wavelength or frequency

Amplitude is one-half the range from crest to valley over which the sine wave varies!

Sine Wave Model of Electromagnetic Energy

- It describes variations in electric & magnetic fields as photon travels with velocity

Frequency

- The rate of rise & fall
- *Symbol*: *f*
- *SI Unit*: hertz (Hz)
- *1 Hz*: 1 cycle/second
- It is equal to the number of crests or valleys that pass the point of an observer per unit time
- It is inversely proportional to the wavelength

Frequency is the number of wavelengths that pass a point of observation per second!

Wavelength (λ)

- Distance from one crest to another
- Distance from one valley to another
- Distance from one point on the sine wave to the next corresponding point
- *Unit*: Lambda (λ)
- Inversely proportional to the frequency

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Three Wave Parameters

- Velocity, Frequency & Wavelength
- Need to describe electromagnetic energy

At a given velocity, wavelength & frequency are inversely proportional!

Wave Equation

- *Formulas:* $\lambda = c/f$; $v = f\lambda$; $f = c/\lambda$
- c : velocity of light
- These are used for both sound & electromagnetic energy

Electromagnetic Wave Equation

- *Formula:* $c = f\lambda$
- For electromagnetic energy, frequency & wavelength are inversely proportional

ELECTROMAGNETIC SPECTRUM

Electromagnetic Spectrum

- A continuum of electromagnetic energy
- *Frequency:* 10^2 - 10^{24} Hz
- *Wavelength:* 10^7 - 10^{-16} m

The electromagnetic spectrum includes the entire range of electromagnetic energy!

Three Regions Important to Radiologic Science

- *Visible light Region:* viewing condition of a radiographic & fluoroscopic images are critical to diagnosis
- *X-ray Region:* fundamental to producing a high quality radiograph
- *Radiofrequency Region:* with the introduction of MRI, become more important in medical imaging
- *Others:* UV light, infrared light, & microwave radiation

Ultrasound

- The wave of moving molecules
- It requires matter
- It cannot exist in vacuum

Diagnostic ultrasound is not part of the electromagnetic spectrum!

Measurement of the Electromagnetic Spectrum

- *Three Scales:* energy (eV), frequency (Hz) & wavelength (λ)

The energy of a photon is directly proportional to its frequency!

Visible Light

- It occupies the smallest segment of electromagnetic spectrum
- It is described in terms of wavelength
- *Range:* 400 nm (violet) to 700 nm (red)

Refraction

- The deviation of course that occurs when photos of visible light traveling in straight lines pass from one transparent medium to another

Sunlight

- *2 Invisible Light:* infrared & UV light

Infrared

- Longer λ than visible light
- Shorter λ than microwaves
- It heats any substance on which it shines (*radiant heat*)

UV Light

- It causes sunburn
- Lies between visible light & ionizing radiation

Radiofrequency

- *Range:* 0.3 kHz-300 GHz
- *Range in MRI:* 1-100 mHz
- Low energy & long wavelength

Microwave

- Very-short wavelength RF
- Higher than broadcast RF
- Lower than infrared

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Ionizing Radiation

- Higher energy & lower wavelength

X-rays

- It is emitted from the electron cloud
- It is produced in diagnostic imaging systems

Gamma Rays

- It comes from inside the nucleus of radioactive atom
- It is emitted spontaneously from radioactive material

The only difference between x-rays & gamma rays is their origin!

Visible light is identified by wavelength, RF is identified by frequency, & x-rays are identified by energy!

Electromagnetic Relationship Triangle

- Formulas: $c = f\lambda$; $E = ch/\lambda$; $E = hf$

WAVE-PARTICLE DUALITY

Visible Light Photons

- They behave more like waves

X-ray Photons

- They behave more like particles

Wave Particle duality

- The principle that states that both wave & particle concepts must be retained, because wave-like properties are exhibited in some experiments & particle-like properties are exhibited in others

Photons interact with matter most easily when the matter is approximately the same size as the photon wavelength!

Radio & TV Waves

- They are measured in meters
- They interact with antennas

Microwave

- It is measured in centimeter
- It interacts with hotdogs & hamburgers

Visible Light

- It is measured in nanometer
- It interacts with rods & cones of the eye

UV Light

- It interacts with molecules

X-rays

- It interacts with electrons

Wave Phenomenon

- All radiation with λ longer than x-rays

X-rays behave as though they are particles!

Wave Model: Visible Light

- Sense by human eye
- Short wavelength (violet) to long wavelength (red)
- The difference in wavelength is proportional to the energy introduced into the system

Visible light behaves like a wave!

Electromagnetic Energy Attenuation

- The reduction in intensity that results from scattering & absorption

Interaction Between Light & Absorbing Material

- *Transparency*: not at all (*transmission*)
e.g. window glass
- *Translucency*: partially (*attenuation*)
e.g. frosted glass
- *Opacity*: completely (*absorption*)
e.g. black glass

Radiopaque

- The structures that absorb x-rays
e.g. bones

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Radiolucent

- The structures that transmit x-rays
e.g. Lung tissue

Inverse Square Law

- It states that the intensity of radiation at a location is inversely proportional to the square of distance from the source of radiation
- Formula: $I_1/I_2 = (D_2/D_1)^2$

Electromagnetic energy (radiation) intensity is inversely related to the square of the distance from the source!

Source of Electromagnetic Energy

- Line Source:** inverse square law does not hold at distances closes to the source

The inverse square law can be applied to distance greater than seven times the longest dimension of the source!

Particle Model: Quantum Theory

- X-rays are identified by their energy (eV)
- Energy: 10 keV-50 MeV
- Wavelength: 10^{-10} - 10^{-14} m
- Frequency: 10^{18} - 10^{22} Hz
- All electromagnetic radiation can be visualized as two perpendicular sine waves (*electric & magnetic fields*) that travel in a straight line at a speed of light

The x-ray photon is a discrete bundle of energy!

Planck's Quantum Theory

- X-rays are created with the speed of light (c)
- X-rays exist with velocity or they do not exist at all

Max Planck

- He synthesized our understanding of electromagnetic radiation
- 1918: He received the Nobel Prize

Planck's Constant

- Symbol: h
- Constant: 4.15×10^{-15} Evs or 6.63×10^{-34} Js

Planck's Quantum Equation

- Formula: $E = hf$
- Equivalent Equations: $f = E/h$; $E = hc/\lambda$

The energy of a photon is directly proportional to its frequency!

EXAMPLES OF WIDE RANGE OF X-RAYS PRODUCED BY APPLICATION IN MEDICINE, RESEARCH, & INDUSTRY

Type of X-ray	Approximate Energy	Application
Diffraction	<10 kVp	Research
Grenz rays	10-20 kVp	Medicine
Superficial	50-100 kVp	Medicine
Diagnostic	30-150 kVp	Medicine
Orthovoltage	200-300 kVp	Medicine
Supervoltage	300-1000 kVp	Medicine
Megavoltage	>1 MV	Medicine & Industry

MATTER & ENERGY

Law of Conservation of Matter

- It states that matter can be neither created nor destroyed

Law of Conservation of Energy

- It states that energy may be transformed from one form to another but cannot be created or destroyed
- Total amount of energy is constant